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DYNAMIC DESIGNING OF DENTAL PROSTHESES

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1. Introduction

In our aging society, advances in everything related to health have become more important and should be prioritized. Over the past few years, design in dentistry has improved greatly. Not long ago, prosthetics were designed by hand in laboratories. Today there is a growing use of computer-aided design. Therefore, the use of accurate design processes, new materials and advanced technologies in dentistry is of vital importance for the future. In this sense, the integration of engineering and mandibular dynamics (dynamic occlusion) in the dental CAD/CAM systems greatly contributes to healthy aging patients. Today, many researches are focused on the development of the complete dental digital workflow [Van der Meer et al. 2012], [Brawek et al. 2013].
This change to computer aided design involves great changes in the design phase and throughout the digital workflow. However, there are still some areas that need to be improved, such as taking interocclusal forces into consideration for the design of dental prostheses.
Dental occlusion [Podoloff and Benjamin 1989] studies the contacts between the occlusal surfaces. Ideally, these contacts occur simultaneously and uniformly distributed in the dental arch [Cohn 1962]. Consequently, incorrect occlusion can cause a wide range symptoms to patients: discomfort in teeth, neck pain or back pain [Dawson 1974]. Although dentists had no devices to measure contacts over time, they have tried for years to achieve repeatable, simultaneous, and well distributed contact patterns in their patients, using a conventional methodology. The only techniques they could count on were the articulating paper (carbon paper) or wax [Gazit et al. 1986]. Although these techniques can reveal the location of one static contact (on a tooth or in models), they cannot predict when these contacts will take place. Nevertheless, dentists are particularly interested in the specific dynamics that occur for each occlusion, this is, whether the contacts occur while chewing, in laterotrusion, in protrusion, or in the first contact of the occlusion.
Conventionally, the forces were calculated approximately by observing the size of the ink mark left on the teeth using articulating paper or the depth of the hole in the wax. Some years ago, different digital procedures were developed. Among these procedures, the most popular are Prescale and T-Scan. Prescale film is used to measure contact pressures. The film structure consists of micro-encapsulated color forming and developing material and when pressure is applied to the film, according to the pressure level and to its distribution a red color impression with a varying density is formed. The Fuji Digital Analysis System for Prescale combines dedicated software that converts Prescale density values into pressure values. However, this tool is not able to offer the registration over time, which is a critical factor for many dentistry applications.
As mentioned above, the other most popular procedure is the T-Scan device, which can determine the location and relative intensities of the forces over time. Although there are contradictory statements in

terms of precision and repeatability, the T-Scan device has been used for several decades. Some studies [Komari 1987], [Cartagena et al. 1996], [Commer et al. 2000] argue that the location of occlusal contacts is not sufficiently precise, posing a problem in functional diagnostics. It is also true that the system has improved over the last years, and some relatively recent studies [Millstein 1983], [Reiber 1989], [Filtchev and Kalachev 2008] argue that this device offers a high reliability in diagnosing the existence of occlusal contacts.
However, there are many authors who have reported that these sensors do not offer the same accuracy as conventional methods, and the location of the contacts is less precise than when using articulating paper. This explains why the clinical use of T-Scan is not so much of a common practice. In addition, a decrease in the sensors' sensitivity is observed when used more than once [Kerstein 2008], [Stern and Kordass 2010].
The other device used in this study is the intraoral scanner, which for several dental companies is the centre of their development efforts. Its use is becoming more common in clinical practice, and different studies [Cabral et al. 2006], [Mehl et al. 2009], [Gümüş et al. 2013] have examined the accuracy of digital intraoral impressions. Despite having demonstrated sufficient accuracy in the scanning of individual parts, it has been demonstrated that when working with a full arch, intraoral scanners are not accurate enough [Garino and Garino 2011], [Cuperus et al. 2012], [Patzelt et al. 2014]. This is because of the great amount of "best-fit" alignments necessary to obtain the full arch. If an error is introduced in each alignment the accumulated error is far too high in the resulting full arch. This problem has been studied extensively in recent years by different authors [Ender and Mehl 2011, 2013], [Grauer and Proffit 2011], [Akyalcin et al. 2013], [Andriessen et al. 2014]. In the latest versions, this problem has been partially overcome, reaching a deviation for a full arch of around 0.127 mm [Van der Meer et al. 2012].
Taking all of this into account, the research at the Laboratory of Product Design at the University of the Basque Country (UPV/EHU) aimed to integrate reverse engineering and mandibular dynamics, presenting a new methodology for clinical application.

2. Methodology

Dynamic registration was considered important for this study. This accounts for the use of the T-Scan system in this study. This device uses a thin, flexible sensor in order not to distort the information regarding occlusal contacts. It is a tactile sensor resistive ink consisting of two sheets (Figure 1a). The physical principle of this is that the circuit of the sensor detects the capacitive variation, when pressure is made. The sensor is configured with 44 rows and 52 columns with a spatial resolution of 1.27 mm and a thickness in the detection area of 100 microns (articulating paper thickness range: 8-200 microns) and obtains the required information every 0.01 seconds. These sensors give a colour-value (in a 256-color scale) to each pixel (Figure 1b) and this can be seen as a 2D contour (Figure 1c).
T-Scan sensors are comparable in thinness to that of the articulating paper used nowadays. The articulating paper determines the location of the marks (contacts areas). However, T-Scan puts articulating paper marks into context with timing and force so that dental practitioners can provide a more confident, proactive approach to patient care that leads to better outcomes.

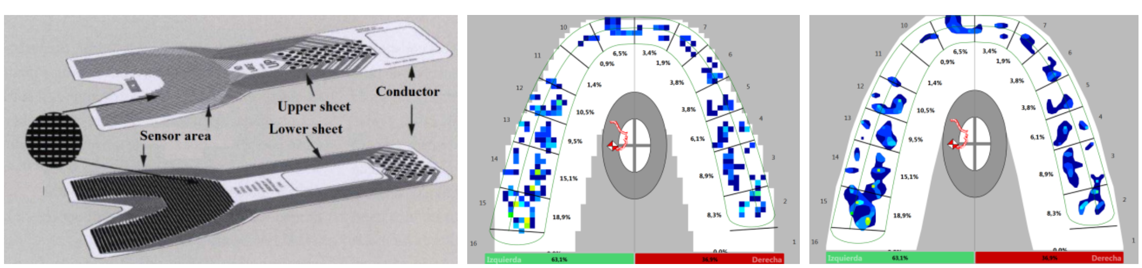

Figure 1. T-Scan sensor: a) parts of the sensor, b) result of a T-Scan registration as pixel representation, c) as 2D contour representation

The experiments were carried out in 2 phases. In the first one, 3 cases were mounted with plaster models on a mechanical articulator (in vitro) and the occlusal contacts were obtained in maximum intercuspidation by using articulating paper (Figure 2a) and a T-Scan (Figure 2b).

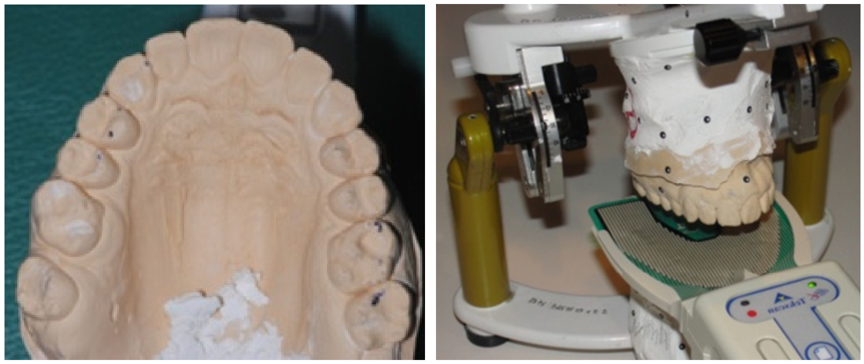

Figure 2. In vitro experiments: a) occlusal contacts on plaster model, b) T-Scan registration

In a second phase, 3 more cases were carried out in vivo. The occlusal contacts were obtained directly in the mouth by using articulating paper, the arcades were scanned with intraoral scanner (Figure 3a) and the contacts were obtained with the T-Scan (Figure 3b).

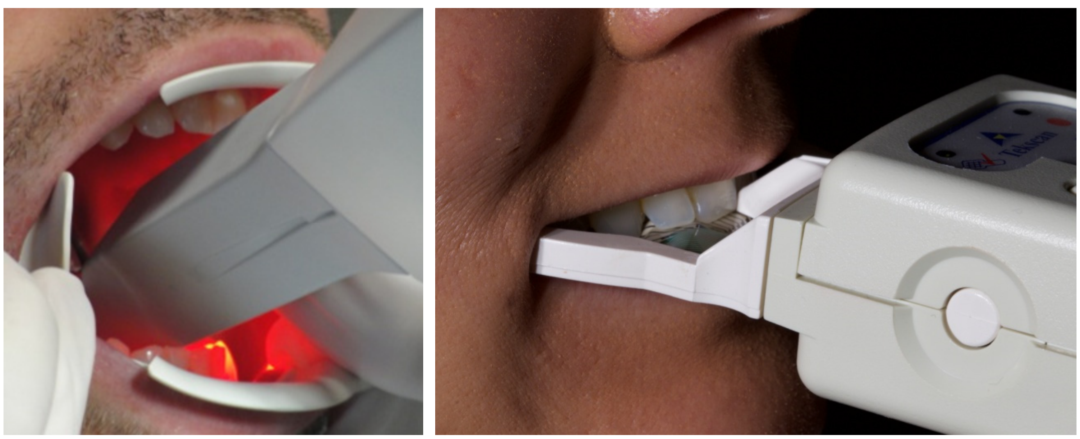

Figure 3. In vivo experiments: a) intraoral scanning, b) T-Scan registration in vivo

The most important aspect of the projection is the alignment between the scanned mesh and the image of the T-Scan. For that, the scanned mesh was transformed into a CAD surface using the Geomagic Studio 2013. In the Solid Edge ST6 program, the image was positioned in reference to the CAD surface of the denture. In Geomagic Studio 2013, the image was aligned to the mesh by selecting the equivalent contacts. Then, the contacts were projected in the mesh of the occlusal surface (Figure 4).

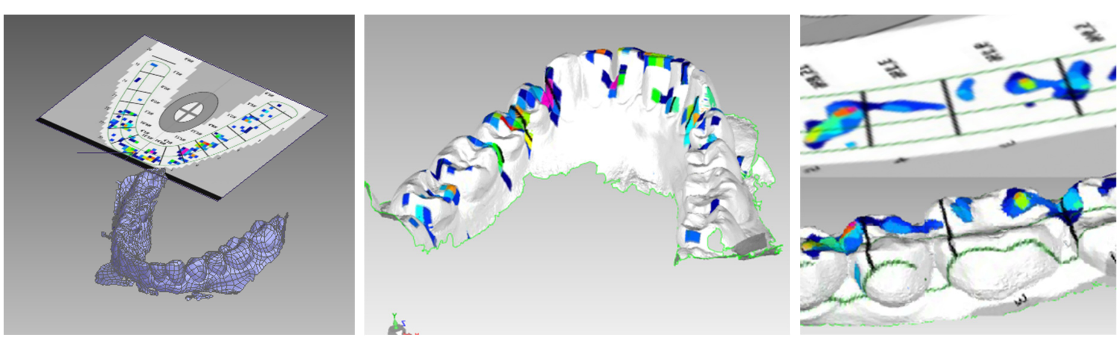

Figure 4. Projection: a) alignment, b) lingual view of the projection, c) zoom of the projection

Finally, the results obtained conventionally (using an articulating paper) were compared with the ones obtained with the proposed methodology. For that, and in order to have a more accurate comparison, the mouth picture also was projected onto the occlusal surface (Figure 5).

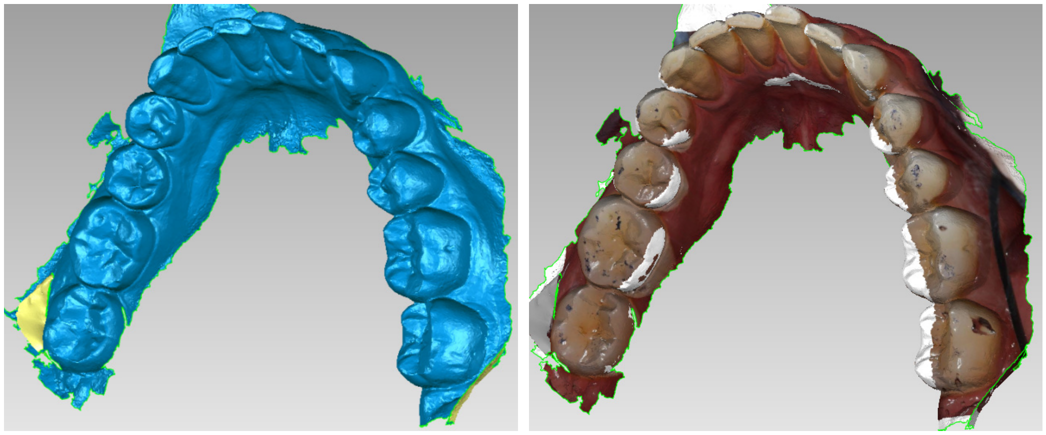

Figure 5. Conventional contacts projection: a) digital occlusal surface, b) conventional contacts projected on the occlusal surface

3. Results

After these experiments in vitro (cases 1-3) and in vivo (from 6 different patients) were carried out, the reliability was determined by analyzing the coincidence of contacts (Table 1). The T-Scan contact marks were bigger (sensel area) than the conventional marks. The conventional contacts were identified and counted and then the coincidences with the T-Scan contacts were determined. However, both procedures were projected on the 3D digital model and the comparison was made on the same 3D surface. This makes the comparison of the contacts more reliable. The 3 in vitro cases resulted in an average value of 80.6%, while the in vivo cases was 75.6%. In general, a 78.1% (average value) reliability was reached.

Table 1. Coincidences in 6 cases (case 1-3 in vitro)

CASES	Conventional contacts (articulating paper)	Coincidences (T-Scan- art. paper)	Coincidences (%)
1	26	15	58%
2	19	18	95%
3	19	17	89%
4	20	14	70%
5	13	11	84%
6	15	11	73%

4. Discussion

The most important requirements for the clinical applicability of a measurement system are, on the one hand, the measured values representing the true value as precisely as possible and, on the other, the fact that the measured values differ slightly in repeated measurements (this is to say, repeatability). Several studies [Kerstein 2008], [Stern and Kordass 2010] state that the device is sufficiently reliable in terms of occlusal contacts because it can be used to verify the existence of contacts and to measure them in percentages. However, these studies do not determine the accuracy of the location of occlusal contacts and forces. In other words: it does not state where and when the occlusal contacts exactly occur, and this is certainly a very significant information for any dentist or dental technician.

The variability and repeatability of the measured values depend on the individual. Factors such as tooth mobility factors, periodontal altered reaction to repeated loading, torsion of the jaw and a load angle altered by jaw movement will certainly have a decisive influence in the measured results.
It can also be pointed out that external influences such as changing the sheet (sensor) do not have much influence on the results. The influence of repositioning the device for repeated measurements, as well as the influence of the change of the sheet (sensor) are only significant for clinical applicability. The selected measurement protocol simulates important potential sources of error that can occur during the clinical procedure: a possible change in the patient's occlusion pattern, the deformation of the leaf in frontal teeth as well as the accuracy of the articulating paper were some other variables considered before the study. However, it is true that the obtained average values were 80% and could be improved making an individual alignment between the T-Scan image and the 3D model. This will be the next step of this research line. Besides this, the precision of the T-Scan sensor would improve the results of this methodology. The 1 mm square sensel should be reduced for the purpose of having the same accuracy as the articulating paper positioning accuracy.
This study analysed the feasibility of the methodology and demonstrated its functionality. The resolution, accuracy and repeatability of the method should be determined in a subsequent study.

5. Conclusions

The proposed methodology provides more objective and meaningful information to the dental professional for diagnosis, planning and treatment, especially for the design phase. For the design phase is critical to know where and when the forces occur during the occlusion. This integration can be applied to different fields in dentistry. In principle, implants and prostheses seem to be the most significant fields which could benefit from this this integration.
The presented methodology also shows that although it can provide significant qualitative results, the locations of occlusal contacts should be calculated in order to state whether they are precise enough for the different fields of dentistry.

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